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of

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for

MULTI-FACETED GASIFIER AND RELATED METHODS

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MULTI-FACETED GASIFIER AND RELATED METHODS

Cross-reference to related application

This application claims the benefits of U.S. Provisional Application No. 60/251,076, filed
5 December 4, 2000.

Field of the Invention

The present invention relates generally to gasification of carbon-containing fuels and more particularly to novel gasification apparatus and methodology for the gasification of carbonaceous feedstocks that incorporates both fixed-bed gasification processes and entrained-flow gasification processes in one vessel. Optionally, fluidizing principles may be utilized in the gasifier. Internally generated activated carbon char may be used as the principal sorbent for synthesis gas cleaning to produce an environmentally superior synthesis gas (syngas). The present invention is able to receive and process coarse fuels in the fixed bed sections and pulverized or fine solids, as well as liquid and gaseous feedstocks in the entrained flow section.

Background of the Invention

Broadly, gasification is the creation of combustible gas known as synthesis gas and commonly referred to as "syngas" herein, from carbon-containing fuels. Gasification is a well-
20 known industrial process used for converting solid, liquid and gaseous feedstocks using reactants such as air, oxygen, and steam into gases such as hydrogen, carbon monoxide, carbon dioxide, and methane. The resulting gases can be used for generating electrical power, producing heat and steam, or as a feedstock for the production of various chemicals and liquid fuels, or any combination of the above. To appreciate the present invention, it will be helpful to have an understanding of the history
25 of gasification and current limitations of prior art in commercial gasification technologies.

Various forms of gasification have been used since the 1800's as a way to convert solid fuels (primarily coal) to gaseous fuel (synthesis gas or syngas). Large-scale coal gasification was first applied as a way to generate town-gas, distributed through pipeline systems throughout much of Europe prior to the development and use of natural gas.

The oldest gasification processes is known as fixed bed (or moving bed) gasification. The Germans originally developed fixed bed gasification and subsequently the first large-scale fixed bed coal gasifiers. Additional processes including fluidized bed gasification and entrained bed or entrained flow gasification processes have been developed more recently by others. All three gasification processes have both beneficial as well as limiting features, which the following discussion will generally describe.

Fixed-bed gasification requires coarse fuels (typically ¼" to 2" in diameter). The most well known and widely used fixed-bed gasification technology is the Lurgi Dry Ash gasifier (the ash is recovered dry and does not turn molten or slag). The Lurgi Dry Ash technology is presently used by the country of South Africa, to convert large reserves of coal into syngas, which is then converted to liquid fuels and chemicals via downstream syngas catalysts. Nearly half of all transportation fuels used in South Africa come from the Lurgi-based coal gasification plants in that country. Presently, there is one Lurgi-based gasification installation in the United States that converts lignite (high moisture, low rank) coals to syngas, which is then subsequently converted to pipeline quality methane and sold into the natural gas pipeline system. An advantage of the Lurgi gasifier is its ability to produce a syngas with a ratio of hydrogen to carbon monoxide greater than two. This allows the syngas, after cleaning, to be used in downstream conversion processes to make liquid fuels and chemicals that require this higher ratio.

Fixed-bed gasification uses coarse fuels, which first must be devolatilized (i.e. drive off all volatile compounds) before gasification of the remaining fixed carbon occurs. The carry over in the syngas of tars and oils from the Lurgi Dry Ash gasifier led to the development of the British Gas Lurgi (BG/L) fixed-bed slagging gasifier. While it too carries over tars and oils with the initial raw syngas effluent, the BG/L has the ability to re-circulate and re-inject the tars and oils into the hotter lower slagging (molten ash) section of the gasifier, where the tars and oils are converted into syngas constituents. The reinjection of tars and oils is an unnecessary additional step that is eliminated by the present invention. It would be an advancement in the art of fixed-bed gasifiers to provide a gasification system that prevents the creation of tars and oils in the raw syngas effluent.

Limiting technical features of fixed-bed gasification include: (1) tar and oil carry over with the syngas; (2) difficulty in using coal/fuel fines because they clog the void space between the coarse fuels in the fixed bed (because of this, large piles of discarded coal fines are stockpiled adjacent to

these plants or transported off-site to combustion facilities that can use the fines, resulting in low overall coal-to-product efficiencies); (3) difficulty in using liquid hydrocarbon feedstocks; and (4) difficulty in using caking coals (coals with low ash fusion temperatures) which often require mechanical stirring to agitate the fuel bed.

5 A newer gasification process is known as entrained-flow or entrained-bed gasification. Pulverized solid fuels and/or viscous liquid fuels are fed to the gasification reactor and are rapidly converted to syngas. One major advantage of the entrained-flow gasification processes is that no oils and tars are produced, precluding their presence in the effluent syngas.

Another advantage of the entrained-flow gasification process is its ability to gasify liquid feedstocks (i.e. oil or heavy oil residuals from refineries). The primary entrained-flow gasification technologies include those developed by: Texaco, Shell and Dow Chemical (Destec). Entrained-flow gasification processes are unable to easily process coarse fuels. This makes it difficult to process certain fuels, such as biomass and segregated municipal solid waste or scrap tires (fuels that cannot be economically pulverized for use as fuel). Another limitation of entrained-flow gasification is the inability to achieve wide internal control of the hydrogen to carbon monoxide ratio in the exiting syngas. To adjust this ratio in favor of hydrogen would require an additional downstream water gas shift reactor to increase hydrogen and reduce carbon monoxide.

Entrained-flow gasification technologies also have technical and fuel processing limitations. In order to convey the fuel into the gasifier, some entrained flow gasifiers use a slurry feed that is often water mixed with pulverized solids at approximately a 1:2 ratio respectively. Other commercial entrained flow gasifier use dry feeds pulverized solid into the gasifier. All these gasifiers produce a syngas with a hydrogen to carbon monoxide ratio of approximately 1:1 or less with limited ability to control this ratio. Gasifiers using the slurry feed process for solids feedstocks limit their ability to use high moisture fuels such as lignite coals as too much moisture fed to the gasifier system results in poor gasification performance.

In addition to the limitations cited above, other prior art problems include: (a) clogging, caking and/or undesired accumulations of material in the fuel delivery, bed and/or slag discharge regions of the gasifier; (b) inadequate sulfur and pollutant species control requiring the need for extensive syngas cleaning and processing equipment downstream of the gasifier; (c) high installation and operational costs; and (d) limited fuel flexibility.

A third gasification process known as the fluidized bed process has been utilized on a limited basis. Fluidized bed gasifiers also use coarse fuels, however the coarse fuels are somewhat smaller in size than coarse fuels used by fixed bed gasifiers. An advantage of the fluidized bed processes is its ability to use fuels with relatively high ash contents. Fluidized bed gasification processes face challenges related to fuel agglomeration in the bed. In addition, fluidized bed gasification processes realize some similar limitations as fixed bed processes.

To summarize, the principle limitations of prior gasification art include the limited ability to simultaneously process or gasify both coarse and fine solid fuels or simultaneously process or gasify both coarse and liquid hydrocarbon feedstocks resulting in a general lack of fuel flexibility in any one system. While gasification plants are generally able to meet exceedingly high emission limitations, their capital costs remain high. Costs in controlling pollutant species must be reduced to allow its widespread use for many energy or electricity generating plants. The present invention is designed to overcome these challenges.

Brief Summary of the Invention

The present invention is drawn to a continuous gasification process for producing environmentally superior synthesis gas by having internal capabilities of generating activated carbon char as a medium to adsorb well-known pollutants found in synthesis gas streams. Furthermore, this process is capable of using a wide array of carbonaceous fuel types by having both fixed bed and entrained flow gasification processes in a single vessel. Furthermore the present invention is also able to utilize fluidizing features to agitate the fixed bed fuel and/or the ash to optionally increase the carry-over of activated carbon char particulates with the effluent syngas stream. The present invention is preferred to operate as a slagging gasifier.

The present invention prefers to use a dry feeder burner for the entrained flow feed inlet sections preventing the need for a water slurried feeding process. Due to the ability to dry feed the fuels into the entrained flow section coupled with a fixed bed of fuel, the present invention is able to advantageously control the steam to oxygen ratio, which results in the ability to increase hydrogen production from a partial water gas shift reaction inside the gasifier. If desired, further internal temperature moderation using steam can encourage subsequent methanation reactions to increase the methane content of the syngas. Having control over the hydrogen to carbon monoxide ratio

eliminates or mitigates the need to have additional water gas shift reactors and / or secondary gasifiers downstream of the main gasifier. This can improve overall plant economics when producing products that require a higher ratio, such as methanol, ammonia, methane or liquid fuels via various catalysts and downstream processes that utilize synthesis gas.

5 The coarse fuel is fed to the top of the gasifier where the fuel bed elevation is self-regulating by three step changes in bed diameter. The first step change is close to the top of the gasifier where coarse fuel enters and slopes to the fuels' angle of repose. This upper section represents the downdraft gasification section of the fixed bed section of the gasifier, hereinafter referred to as the hood. In the hood, coarse fuels devolatilize before being converted to activated carbon char near the
10 bottom of the hood, where temperatures are raised to just below the ash fusion point of the coarse fuel. Injecting additional air or oxygen and steam may sufficiently eliminate tars and oils. The inclusion of the hood apparatus within the main gasifier vessel forms an upper plenum around the outside of the hood where the synthesis gas has an exit port. All upper fixed bed gasification gases must pass, in downdraft fashion, or concurrently with the fuel, around the lower lip of the hood
15 before entering the upper plenum and exiting the gasifier at the exit port.

The hood may be a steel cylindrical insert with supporting lower inwardly converging edges that hold the ceramic material used in lining its interior. To ensure proper cooling and temperature control of the steel on the hood, bayonet tubes may be used on its exterior with circulating water.

After the fixed carbon char passes below the bottom lip of the hood, the coarse fuel then
20 again flows outward forming another angle of repose toward the interior wall of the ceramic lined main gasifier shell.

Another internal step change begins in the same area forcing the coarse fuel to converge as it moves downward toward the lower fixed bed section of the gasifier. The purpose of the ceramic lining to downwardly converge in diameter is to create a lower annular plenum surrounding the
25 lower fixed bed fuel, for which to receive the gases from the entrained flow gasification section using tangentially fired burners. As the coarse fixed carbon char moves downward below the hood, gases flow in an updraft fashion countercurrent with the fuel. The fuel continues to move downward toward the ash slagging region where the molten ash is removed through a slag tap at the bottom. Wherever the coarse fuel touches the ceramic lined portion of the gasifier, a plurality of orifices may
30 be used to fluidize or agitate the coarse fuel or ash.

The entrained flow gasification section can feed fine or pulverized solids, liquid or gaseous fuels, or any combination thereof. The entrained flow section may process approximately twice the fuel that is fed to the fixed bed section. Gases from the entrained flow section work their way upward through the lower fixed bed mixing first with the gases derived from the lower fixed bed, then continuing to move upward ultimately mixing with the gases exiting from the hood section. All gases blend in the upper plenum before exiting the gasifier. The upper plenum also acts as the means to control the residence time and temperature of the gases before exiting to ensure destruction of tars and oils.

In addition, the gasifier can extract activated carbon char from the gasifier in two ways. One is to intentionally carry over carbon particulate with the syngas effluent which is then separated by a particulate removal system. The second is to have an extraction port in which coarse fuels from the mid section of the gasifier are extracted. The latter method is only used if the volume of material carried out as particulate cannot supply enough activated carbon char to the downstream baghouse system to meet desired pollution adsorption rates and efficiencies.

In summary, the present invention overcomes or substantially alleviates many problems heretofore existing in the gasification art. The present invention comprises both novel apparatus and unique methodology for the gasification of carbonaceous feedstocks to produce an environmentally superior synthesis gas (syngas) combining fixed-bed gasification processes and entrained-flow gasification processes into one vessel. Optionally, fluidizing principles may be utilized to pulsate the coarse fuels and/or ash in the bed. In addition, the gasifier's fixed-bed component combines both downdraft gasification and updraft gasification. Superior operating characteristics within the gasifier are achieved increasing chemical and thermal efficiencies while lowering costs for syngas production. The gasification process represented in the present invention is highly fuel-flexible and able to utilize both coarse and pulverized solid fuels, as well as liquid or gaseous feedstocks or any combination thereof. The hydrogen-to-carbon monoxide ratio in the syngas is readily controlled from a range of 0.5:1 to 3.3:1. Internally generated activated carbon char creates an adsorbent medium for removing pollutants from the syngas including, but not limited to, sulfur species, mercury, chlorides and others. Clogging and caking are minimized, tars and oils are eliminated within the gasifier and are not carried out with the raw syngas, and high process efficiencies are obtained resulting in lower costs for equipment, installation and operating costs. These and other

objects and features of the present invention will be apparent from the detailed description taken with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a cross-sectional representation of a gasifier within the scope of the present invention.

Figure 2 is also a cross-sectional representation of the gasifier with additional numbers.

Figure 3 is also a cross-sectional representation of the gasifier with additional numbers.

Figures 4 and 4A are cross-sectional drawings that represent the internal hood in the upper fixed-bed section of the gasifier.

Figure 5 is a plan view of the gasifier showing the tangentially fired burners.

Figure 6 is a cross-sectional view of a typical burner that may be used.

Figure 7 is a process flow diagram depicting how activated carbon char may be collected from the gasifier for use as a syngas cleaning sorbent.

Figure 8 is a cross-sectional view of the gasifier depicting how the pulsing system may be located in the gasifier.

Figure 9 is a diagram of the pulsing control center.

Detailed Description of the Invention

Reference will now be made to currently preferred embodiments of the invention, which are illustrated with figures. In the illustrated embodiment, shown in Figure 1 a cross sectional view of the gasifier 1, is shown. Coarse sized carbonaceous feedstock enters at the top of the gasifier, through a coarse feed inlet 2 and proceeds downward moving through gasifier 1 until it becomes a molten ash at the bottom 3. Coarse feedstocks can include, but are not limited to, the following: coal, petroleum coke, municipal solid waste, biomass, or any combination thereof. Below the coarse feedstock inlet 2 the fuel enters a pyrolysis zone, labeled 4 at the top of the zone and 5 at the bottom of the zone. In the pyrolysis zone the coarse fuel is heated by a combination of combustion and gasification, which causes the coarse fuel to devolatilize. The combustion oxygen or air and steam needed for pyrolysis enter through several ports 6 by passing through pipes 7. The amount of oxygen or air added at port 6, is set to keep the temperatures at point 4 between 500°F and 1500°F and

preferably above 700°F and at point 5 between 800°F and 1500°F, and preferably approximately 1200°F. At points around the ports 6 a hot combustion flame may occur as the oxygen or air burns with the pyrolysis gases coming off the fuel. As the gases spread throughout the pyrolysis zone 4 to 5 the gas temperatures moderate.

5 Like other downdraft fixed-bed gasification processes, both the fuel and pyrolysis gases move downward. This downward gas movement causes the pyrolysis gases to pass through an oxidation gasification zone between points 8 and 9. At inlet ports 10, more oxygen or air and steam enter the gasifier to raise the temperature of the gases to a temperature a margin below the ash softening point of the fuel at the throat 11. Several pipes 12 may carry the oxygen or air and steam to the ports 10. For typical coals, the ash softening point ranges from 1900°F to about 2400°F. During operation the maximum peak temperature in the throat 11 zone is maintained at least 50°F below the ash softening point, with 100°F below as the normal maximum condition.

As the pyrolysis gases pass through the combustion zone at throat 11 and out to the exit of the bed at point 9, most if not all the tars and oils are destroyed and converted to syngas. The main chemical constituents of syngas are hydrogen, carbon monoxide, methane and carbon dioxide. The section of the gasifier from the fuel entry 2 to the designated point 13 is called the hood section or the upper fixed bed section. The gases from the hood section leave the coarse fuel bed at point 9.

20 On leaving the bed the gases pass up the annular plenum 14. The volume of the plenum 14 is sized to provide sufficient residence time of the gases to destroy and convert any remaining tars and oils to syngas before they pass out of the gasifier through exit pipe 15. A typical residence time will be at least two seconds for applications where the slightest levels of tars or oils are not permissible. Furthermore, the steam to oxygen or air ratios and flows are adjusted to keep the temperature at bed exit 9 in the range from 1000°F to 1600°F and preferably at about 1550°F when operating for a near zero tar and oil carry over from gasifier. This combination of high temperature and residence time
 25 for two or more seconds has been shown in test programs to completely destroy all tars and oils.

One important feature of the hood section is the ability to control the amount of oxygen or air and steam introduced at ports 6 and ports 10. This allows the temperature of the coarse fuel to be raised sufficiently high to ensure complete devolatilization of the fuel and destruction of all tars and oils before they exit the hood section at location 13. The hood section between points 2 and 13
 30 represents the first stage of a two-stage, fixed bed within the gasifier. As the coarse fuel reaches the

environment is simplest and least expensive cooling method. The inside of the vessel preferably includes a ceramic liner 21 for the main vessel and a ceramic liner 22 for the hood section of the vessel. The ceramic covers all areas where excessive temperatures exist. With properly designed ceramic liners 21 and 22, radiant cooling to the environment is acceptable. Force draft cooling using air is the next simplest and most economic cooling method. To do this, a shroud is built around the vessel and air is forced through the shroud. For applications where a slight efficiency improvement is desirable, and representing the third method of cooling, the vessel can be water jacketed to make steam for use in the gasifier or in the rest of plant.

On the inside of the gasifier 1 the internal shape of the ceramic liners 21 and 22 are important to the success of the gasifier. In Figure 3 the internal cross section of the ceramic bottom surface 23 is shown. Surface 23 provides a cone shaped slope for molten ash to run toward the molten ash extraction hole 24. An oxygen port 25 and gaseous fuel port 26 (more than one each can be used) are provided to create a hot flame to keep the ash in a molten state in the extraction hole 24 by firing as needed. The gaseous fuels can be any of several including recycled syngas, propane, or natural gas. In some applications even oil can be used. When the molten ash passes through the hole 24 it slides over a ceramic disk shaped plate 27. Plate 27 is sloped to cause the molten ash to slide off the plate 27. As the drops from the plate 27 it falls into a water bath 28 where the molten ash solidifies. As the solidified ash drops through the water bath 28 it has to pass through a clinker grinder 29 which crushes the ash to a size that it can be hydraulically conveyed to a ash storage tank. Persons skilled in the art will appreciate that a wide variety of alternative ash collection and handling systems may be used herein.

A steam vent 30 on the side of the vessel removes the steam formed by the ash and prevents the steam from excessive streaming through the molten ash extraction hole 24 which could lead to ash solidification in the hole 24. The steam coming from vent 30 is used to provide part of the gasifier's steam requirements. The spacing between ceramic plate 27 and the bottom of hole 24 is adjustable. Collection of molten ash into dry, non-water bath containers can also be used, but it is not discussed herein.

Above the cone shape ceramic section 23 the ceramic liner 21 may be shaped to form a restriction zone 31. This creates a cavity below the ceramic liner at point 32 forming a lower annular plenum around the lower fixed bed of coarse fuel. The gases from the tangentially fired burners 19

enter the angular pocket at opening 18. The gases circle around the lower plenum 32, and enter the bed of fuel.

Above restriction 31 the ceramic surface 33 is also preferably cone shaped. The coarse fuel bed from the hood bottom opening 13 is a smaller area than the ceramic surface 31 below it. This causes a natural bed free surface between ceramic surface 33 and hood exit area 13. The free surface at point 9 is where all the gases leave the bed from both the hood section and the lower fixed bed section. They pass through upper plenum zone 14 before exiting the gasifier at the exit pipe 15.

The ceramic used at surfaces 33, 32, 31 and 23 and in the hood is preferably a high temperature, high quality ceramic, like Zirchrom 90 produced by Saint-Gobain Industrial Ceramics. Zirchrom 90 has an operating temperature over 2800°F and is composed of 86% Cr₂O₃ and 7% ZrO₂. The ceramic is made of sized blocks for assembly in the vessel. The ceramic liner is supported by vessel wall 20 and the vessel domed bottom 34. Cheaper less heat resistant ceramic is preferably used as liner material between the vessel 20 and the high temperature ceramics that form the inside surfaces. For the ceramic surfaces 35 and 36 a less expensive ceramic may be used like AL100 which is Al₂O₃. In the hood section a high quality ceramic like Zirchrom 90 may be used in the high temperature surface zones, designated points 37 and 38, and a ceramic like AL100 in the low temperature ceramic surface 39.

Figure 4 shows the hood section 40 of gasifier 1. A cone-shaped steel section 41, supports the ceramic liner 22. This is shown better in Figure 4A, which is an enlargement of the bottom left corner of the hood 40. The cone section 41 forms the bottom of the hood 40 and is preferably welded to a vertical steel cylinder 42. The cylinder 42 is preferably welded to hood vessel top 43. A number of vertical axis bayonet tubes 44 may be welded around the circumference of cylinder 42. The bayonet tubes penetrate through the domed vessel top 43. A small diameter tube 64 is preferably in the center of each bayonet tube to allow boiler water to pass down the tube. The bayonet outer tube 44 may be bent at the bottom and welded to the cone section 41. The inner tube 64 stops at the bend point. Normally water entering the inner tube 64 of the bayonet tubes is close to the water boiling point for the water pressure used. As the water passes up the outer bayonet tube 44 the heat transfer causes the water to boil and form a two-phase mixture of water and steam. These bayonet tubes 44 cool the steel cone 41 and steel cylinder 42, keeping them within their ASME

coded material strengths. The steam may be used for the gasifier's steam inlet needs or in other uses of the plant.

The oxygen or air mixed with steam in pipes 12 may be attached to the steel cylinder 42. There may be many pipes 12 around the annulus of cylinder 42 that provide inlet gases to hood 40.

5 The ceramic surface 45 forms the throat of the gasifier. The throat is a restriction in flow area for the gases formed, which causes the temperature to increase in the throat zone 11. This area restriction and increased operating temperature is designed to prevent oils and tars formed in the devolatilization of coarse fuel from escaping the hood 40. Effluent gases passing through the throat 11 are exposed to temperatures high enough, in combination with the gasification and combustion reactions, to crack and convert oils and tars to the primary syngas compounds, mainly hydrogen, carbon monoxide, methane and carbon dioxide. The ceramic surface 46 is an inverted cone shape surface that is steep enough to keep the bed material against it and allow the gases to expand and limit the associated pressure drop. The region between inlet ports 10 to the throat 45 is the primary combustion zone of the hood section.

10 In Figure 5 a top view of the gasifier 1 is shown. Two tangentially fired burners 19 are shown connecting to the main vessel 20. These two burners 19 partially oxidize and gasify fine or pulverized solid fuels, liquid fuels, or gaseous fuels such as natural gas. The burners typically have a circular cross section with a steel pipe forming the outer wall. The inside of the pipe is preferably lined with a high temperature ceramic 46 shown in Figure 6. Normally the fine or pulverized solid
15 fuels will be carried into the burners by a screw feeder 47. Inlet gases, oxygen or air and steam enter the burner at port 48. There are several known burner designs which may be used herein. A typical burner is shown in Figure 6. The burner has annulus 49 and vanes 50. The critical area of wear in the burners is the ceramic surface 51. The vanes 50 cause the fuel and inlet gases to mix and oxidize and gasify in the zone 52. The fuel rapidly partially oxidizes and gasifies toward the center of the
20 burner while some of the inlet gases continue to move down the wall providing a cooling protective layer for the ceramic. At the end of the burner 18, the gases and remaining fuel enter the plenum zone 17 of the gasifier. At this point the entrained flow gases pass through the lower fixed bed of the gasifier and exit the bed at zone 9 into the plenum 14 before leaving the gasifier at the exit pipe 15.

25 Having the entrained flow gases merge into the lower fixed bed provides the carbon
30 necessary for the entrained flow products to reach gasification equilibrium. Additional steam is

supplied at ports 53 shown in Figure 1, which discharge in the zone designated 54 to control the gasification conditions and the desired temperature at point 9. The steam pipes 55 provide the needed steam. The use of steam at ports 53 provides important control of bed outlet temperature at zone 9, which may promote a partial water gas shift reaction to generate high quantities of hydrogen gases. This is how the hydrogen to carbon monoxide ratio is controlled. When steam is added to bring the bed to the appropriate temperature, hydrogen production may be maximized and gasifier thermal efficiency may be improved. If desired, additional steam can be added to the same zone to encourage cooling and the production of methane gases via a methanation reaction.

Normally gasification reactions slow and stop when temperatures drop toward and below about 1300°F. When steam is used to control the bed at zone 9 to temperatures in the range of 1400°F to 1700°F, tar and oil destruction at plenum 14 may be optimized. If the throat 11 in the upper bed is performing properly, the additional high temperatures in the upper plenum used to destroy tars and oils, may not be needed. Persons skilled in the art will appreciate that the gasifier may be operated under various temperature profiles and various amounts of oxygen, air and steam depending upon the fuel feedstocks and the desired syngas output.

Figure 7 depicts an important novelty within the scope of the present invention. Figure 7 shows how activated carbon char particulate is captured from the either the effluent syngas stream or is extracted directly from the gasifier for use in a downstream baghouse. Figure 7 shows the gasifier 1 with the main components of the syngas cleanup system. In this figure gasifier 1 has an exit pipe 56 that discharges the particulate laden hot syngas into a particulate removal system 57. The syngas then goes on to a heat recovery steam generator 58. The syngas, upon leaving the heat recovery steam generator 58 may be at about 300°F. The syngas then passes into a dual function baghouse 59, which not only removes all remaining particulates but also most all of the gaseous phase pollutants from the syngas including but not limited to pollutants such as: sulfur species, mercury, chlorides, heavy metals and others.

Sized activated carbon char is mixed with the incoming syngas in a mixer 60 just upstream of the baghouse 59. The mixing of the syngas and activated carbon char carries the activated carbon char into the baghouse and lines the bags. The activated carbon collects on the bags in the baghouse 59. This active carbon is very effective in absorbing the various pollutants at these lower temperatures in the range of 275°F to 350°F. Commercial active carbon is very expensive, often over

\$1000 per ton, so it is not normally used for large-scale gaseous fuel cleanup. But in the present invention, the activated carbon char is a byproduct from the gasifier, and it is no more expensive than the fuel it came from.

There are two methods in which activated carbon is created within the gasifier. The first is in the upper fixed bed section of the gasifier at about point 13. The second area is in the entrained flow section. By intentionally sizing the fine solids to a size in which a portion of the particle is not fully gasified but is carried out as particulate with the syngas, this particle will have been exposed to very high temperatures to ensure activation.

The activated carbon char can leave the gasifier in two ways, either entrained with the effluent gas or directly removed from the fixed bed. Fine particles may be entrained with the effluent syngas by originating in the entrained flow section discussed above or from particulate that has broken off of larger coarse fuel from the fixed bed fuel regions. The second method of obtaining active carbon is by extraction tubes 61. The extraction tube is a slanted double pipe that penetrates the gasifier fuel bed just below bed surface at point 9. By creating a slightly lower pressure on the outside end the tube will act as a vacuum to bring the active carbon out. The pipe is double walled with a water jacket between the two pipes to cool the extraction tube 61. If the gasifier produces enough active carbon char entrained with the effluent syngas to meet the pollution control needs, the second method is not needed.

The extracted partially cooled active carbon char is then pulverized 62, before going on to the particulate cooler 63 where it may join with the collected material from the particulate removal system. The activated carbon char is then pulverized to the desired fineness at point 62. Pulverized activated carbon char is then injected into a mixer 60, which carries the active carbon char on into the baghouse 59.

By novelly using internally generated activated carbon char as a product in downstream for syngas cleaning, the present invention provides improved whole plant operating efficiency compared to other gasifier systems. Typically, thermal efficiency is measured by dividing the total amount of energy in the fuel feedstock into the energy in the resulting gaseous fuel output. Since the present invention may extract some of the carbon put into the gasifier as a byproduct, its total thermal efficiency measured by traditional methods would be lower than other comparable systems. A different result occurs by viewing the fuel (coal or other) as part fuel and part sorbent product rather

than as all fuel. When the input fuel is measured, minus the extracted unconverted carbon used as sorbent, the thermal efficiencies of the present invention will be higher. Moreover, when efficiency is measured by the whole plant (including operating costs of downstream equipment required to clean syngas) against other commercial processes, the present invention shows superior overall plant efficiencies.

The fuel pieces in the bed at point 9, Figure 3 of the gasifier are a mixture of ash and fully activated carbon char. The activated carbon char created in the present invention is not blinded by tars and oils that would normally exist in other fixed bed or some fluidized bed gasification systems. Different coarse fuels will have differing degrees of ability to convert to activated carbon. Fuels with lower ratios of volatiles to fixed carbon content may not be as well suited as fuels that have a higher ratio of volatiles to fixed carbon content.

Experience has shown that certain solid fuels in certain temperature ranges have caking properties that prevent them from flowing properly in the fixed bed environments. The ability of coarse fuels to properly move downward can be greatly improved by the present invention by providing small ports at selected sites to cause short duration jets of gas or pulses to agitate the coarse fuel and or ash. The gases selected for pulsating may be steam, recycled syngas, oxygen, nitrogen, air or others. By using several pulse ports in any given area, large pieces of caking fuel can be broken up to ensure continued proper gasification rates. The gas velocity of the gas pulses is preferably sufficiently high to break up the fuel. The ports 65 are designed for gas pulses reaching sonic velocity. In practice the gas velocity may be much less. Figure 8 shows some typical pulse ports 65. The number of ports and location may be varied depending on the fuels selected. For example, one ring of pulse ports 65 is shown at the throat zone 11 and a second ring of pulse ports is shown near the bed gas exit zone 9. They can be located anywhere so as to properly agitate the fuel. The areas mentioned above are regions within the gasifier where fuel caking is probable.

The pulse ports consist of ceramic tubes that attach to pulse pipes 67. The pipes 67 are preferably attached to the vessel wall 20 or to the hood cylinder wall 42. In the case of the hood cylinder wall the pulse pipes may enter the gasifier through the hood top 43. For the vessel, several pulse pipes may enter through a piping port 66 on the side of the vessel 20. Vessel 20 can have several piping ports 66. The pulse piping is preferably attached to the vessel wall for support.

The use of pulsation for bed agitation eliminates the need for mechanical stirrers that are used in some prior fix bed gasifiers. Each pulse port can have varying degrees of pulse duration and frequency.

Figure 9 shows a diagram of how the pulses to pipes 67 may be controlled. Each pipe 67 has a fast acting valve 68 such as a solenoid valve. The valves in each zone are connected to a common gas source 69, which is maintained at a set pressure. A computer controller 70 determines when each valve 68 opens and its duration. By this method the pulses can be adjusted throughout gasifier 1. The gas source 69 to the pulsing ports 65 can be different in both gas composition and pressure for different zones of gasifier 1.

In addition the table below depicts probable operating temperatures anticipated in different zones of the gasifier illustrated in figures 1 and 6.

**Table
Temperature Profile in Gasifier**

| Point | Maximum Temperature F | Normal Temperature F | Minimum Temperature F |
|--------------|----------------------------------|---------------------------------|----------------------------------|
| 2 | 500 | 200 | 100 |
| 4 solids | 1200 | 300 | 200 |
| 4 gases | 1500 | 1000 | 500 |
| 11 | 2200 | 1800 | 1600 |
| 13 | 1800 | 1500 | 1300 |
| 9 | 1600 | 1300 | 1000 |
| 15 | 1550 | 1200 | 800 |
| 54 | 2200 | 1600 | 1300 |
| 18 | 2800 | 1800 | 1600 |
| 3 | 2900 | 2600 | 2200 |
| 48 | 1200 | 800 | 200 |
| 12 | 1200 | 800 | 200 |
| 7 | 1200 | 800 | 200 |

The following describes the presently preferred start up mode of the gasifier 1. The gasifier is first filled with coarse char fuel or fuel in which volatiles have been removed. The coarse char fills gasifier 1 from point 3 to a couple feet above point 2. Above the point 2 normal fuel can be added to the coarse fuel feeding system. Atmospheric temperature and pressure nitrogen gas is circulated through into the gasifier at inlet ports 6, 10, 19 and 25. The gas passes through the gasifier and out through exit pipe 15 and into the separator 57 and then through the heat exchangers 58. The

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superheater section of the heat exchangers 58 is left open to the boiler and the boiler is filled to proper drum level with boiler quality water. The nitrogen is slowly added until operating pressure is reached. The nitrogen on leaving the heat exchangers passes through a small startup blower that circulated the gases back into the gasifier 1 inlet ports 6, 10, 19 and 25. Downstream of the startup blower a burner fires oxygen and natural gas or propane into the nitrogen to slowly heat the gasifier as it circulates (about 100°F). When the water in the boiler reaches operating pressure the superheater outlet valve maintains pressure by venting the excess steam to a condenser. For Integrated Gasification Combined Cycle (IGCC) plants that produce electricity as the primary product, this would be the main condenser of the steam turbine. When the gasifier bed reaches a temperature of about 1000°F, the temperature is held for two hours to allow the temperature across the ceramic walls to properly establish. With the hot nitrogen still circulating, small levels of oxygen are injected at ports 6, and 10 and propane and oxygen are injected at the burners 19 in a small igniter burner. Propane or natural gas is injected at 26 and oxygen at 25. The excess gas after passing through the heat exchanger is flared in the stack. The firing is slowly increased over about six hours to operating temperatures. When gas quality reaches acceptable composition the gas is routed through the baghouse 59, which has been brought to operating temperature by hot bleed gas. The gasifier is now on line at minimum load. The gasifier may be slowly ramped up to full normal operating conditions discussed above.